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RELATIONS BETWEEN RESISTANCE OF FRUIT AND SKIN CHARACTERISTICS IN TOMATO VARIETIES

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SUMMARY:

Varietal differences in physical properties of processing tomato fruits related with resistance are determined. Mean values of skin resistance and firmness are highly correlated with rupture of the fruits by quasi-static compression and by impact. Skin resistance is dependent on the features of the epidermis, studied microscopically.

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INTRODUCTION

In the search for reducing damage and corresponding losses in the mechanical harvesting of fruits and vegetables, it is necessary to: 1) have the technical means of characterizing and measuring this mechanical resistance and its variability; 2) know the varieties of each type of fruits that will resist damage better; 3) provide the plant breeders with the necessary tools to enable them to introduce these optimal characteristics as objectives of their selection efforts.

It is known that resistance of fruits to mechanical damage is related with the mechanical properties of fruits such as : firmness (or, better, characteristic force-deformation or stress-strain constants) and rupture or breaking resistance, both for static and dynamic loads.

In the case of processing tomatoes, numerous works have dealt with the handling losses and types of damage (O'Brien, 1974; O'Brien et al, 1972, 1972, 1978), but few with the characterization of resistance (Miles et al, 1968, Reznicek et al, 1978), obtaining the result that the main component of the resistance of the tomato fruit lies on the skin.

There are numerous reports on skin resistance properties (Voisey et al, 1970, Henry et al, 1974, Murase et al, 1977) trying to relate them with cracking resistance, an important problem in the tomato, but not related directly to mechanical resistance. Working on sour cherries, Fischer et al (1968) made skin puncture tests for determining the mechanical resistance of these fruits.

Strohmaier (1948) related the resistance to puncture of prune skins with their microscopic structure with different thermic treatments given to the fruits. Cotner (1968) asessed differences in epidermal structure for different tomato varieties, differing in their resistance to cracking; this

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resistance, however, was also related to the number of vascular bundles and with the fruit locules (number and size). Voisey et al (1970) related the susceptibility to cracking with cuticle thickness and skin elongation, assessing that there was no positive correlation between resistance to puncture or skin thickness and resistance to cracking. Mel Chih-Yu-Chuh and Thompson (1972) relate once more the susceptibility to cracking with pericarp microscopic anatomy, establishing the importance of both epidermal and subepidermal layers, and the different behaviour of distinct mutant lines, in respect to mechanical resistance and to cracking.

There is no precise information on the variability of the mechanical properties among different varieties of tomatoes, or the characterization of varieties and lines with respect to their likely behaviour in mechanical harvesting and handling.

OBJECTIVES.

Some years ago, a program was iniciated in our laboratory of mechanical properties of plants with the following objectives : 1) to find out the adequacy of different processing tomato varieties for our Spanish conditions and 2) explore the components of mechanical resistance of tomato fruits and the techniques to determine them. Thus, some advances have been achieved in this area (Ruiz Altisent, 1977, Ruiz Altisent et al, 1979). This paper is concerned with the results of the tests specifically related to the components of resistance (skin puncture and force-deformation) and their variability in different varieties.

The objectives of this research were 1) to determine the resistance characteristics of different varieties of processing tomato and 2) relate them with one another and with the behaviour of the fruits in impact and compression.

MATERIALS AND METHODS

The varieties tested in the whole of the tests that were conducted in the last three years were (see Table 1):

1976 (P= puncture) tests : 10 varieties.

1977 (C-P= compression-puncture) tests : 19 varieties.

1978 (C-P-I= compression-puncture-impact)tests: 30 varieties.

For force-deformation measurements the technique used, based on Arnold and Mohsenin (1971) and Fridley et al (1968), was compression with a flat plate on an equatorial zone of the fruit selected as sphere-approaching as possible, and never surpassing 2, 5-3 mm of vertical deformation which in previous tests was shown to be the limit for non-destructive compression. The fruit was supported by a doughnut of a plastic substance, that was adapted to the form of the fruit (Fig. 1). The surface of compression was measured (maximum and minimum diameters) in some of the tests. Previous tests indicated that the linear regression of force (in N) versus deformation (in mm), 3 to 8 points from 1 to 8 N for each fruit, was a good and simple measure of the resistance to compression or firmness of the fruits (Ruiz Altisent et al, 1977 and 1979, and Fig. 2).

All static measurements (force-deformation and puncture) were made: a) using a Chatillon LTCM testing machine, table type, provided with a 9, 8 N (1 kg) gauge, and always at the minimum speed (3, 5 cm/min) for all the puncture tests and 1978 force-deformation tests; and b) using an Instron Universal Testing Machine for the 1977 force-deformation and compression-to-rupture tests. Firmness values obtained with both testing machines were significantly the same when determined on the same fruits.

Skin resistance was measured by puncture, (Fluck and Gull 1972 and Fischer et al 1968). A cylindrical die of 0, 45 mm in diameter with flat base, was used in all tests. Puncture force was recorded for 5 points in the equatorial zone of each fruit (Fig. 3).

For determining puncture characteristics of the skin 1976 (P) tests included 10 fruits of each variety, grown in the open, collected at the ripe stage. Puncture tests were made, and samples (aprox. 10 x 10 mm^2) of skin removed and fixed in phenol-acetic-acid. Then, inclusion in paraf fin, slicing to 12 μ m and safranine-fast-green dying were used (Johansen 1940). In aleatory areas of the slides, width (30 data/variety) and height (8 data/variety) of the epidermal cells, and thickness of the cuticle (8 data/variety) were measured and analized.

For studying the relations between puncture resistance, firmness and compression rupture 1977 (C-P) tests were made on 19 varieties, 12-17 fruits/variety, selected from the field at increasing maturity, from breaker to full colored, and determined after reaching room temperature (this varied from 18 to 25 °C). This test included firmness, puncture and impact.

Compression-to-rupture of the fruits was made with an Instron applying pressure to the fruit, in vertical position, until rupture or crack ocurred (always in vertical direction). Maximum force was recorded, and the surface (s. Fig. 5) of pressure application measured (maximum and minimum diameters, in mm).

Impact resistance was determined by two ways : For previous laboratory measurements, a pendulum was built (Fig. 4). A standard test of number of impacts until damage (cracks > 1 cm) was used for all the fruits, and the mean number as the resistance to impact of each variety. Forfield 1978 (I) tests dropping the fruits (10 fruits/variety) from 70 cm height to a flat metal plate was used, and grading the observed damage as follows : sum of number of fruits with damage plus number of fruits with severe damage (more than one crack or visible loculus), which is defined as index I.

Analysis of variance and correlation and regression analysis was performed in all the tests.

SKIN RESISTANCE

In all the tests made the varieties show a consistent significant difference in puncture resistance. Table 1 shows mean values of skin puncture resistance for all the varieties and all the tests. The overall means for each year are significantly different. In this way, table 2 was prepares, showing relative values of puncture resistance in respect to Petomech II. The repeated varieties show fairly consistent values of puncture force; 1978 values differ more, because they were on samples of fruits grown in normal culture: not overmature and not from the same seed samples. The correlations calculated for these repeated values are all significantly positive. It appears also always a significant effect of different fruits of the same variety, which has not been possible to relate to maturity differences (in the range of full maturity). There was no attempt to differenciate between plants of the same variety, so that some of the differences between fruits can be attributed to variability between plants. There is not any proof to support this, but varieties appear which usually show more variability than others, in all types of characteristics.

In the 1978 (C-P-I) tests, with the highest number of varieties, Duncan's multiple range test shows three groups of varieties in respect to puncture resistance: the "high resistance" varieties, the "low resistance" varieties an an intermediate group with no very significant differences (see Fig. 9).

Figure 5 includes pictures of two of the varieties studied in their histological structure. (From the rest, one was observed and measured, and the two others were lost in the paraffin-including process). One can observe differences in the shape and size of the epidermal cells, as well as in the thickness and between-cells penetration of the cuticle.

This is corroborated by the statistical analysis of the measurements: height and width of the cells, and thickness of the cuticle are significantly different for each variety. Table 3 shows mean values of these parameters, for the seven varieties studied, in relation to puncture force (mean value of the same fruit from which the sample was taken). Correlation coefficients are highly significant for the three parameters with puncture resistance (Fig. 6). It is interesting to note that correlations of these same parameters with mean puncture values of the varieties, are some less close; this result gives further indication that puncture force is determined by these epidermic parameters. These three parameters: height and width of the cells and thickness of the cuticle are interrelated, in the following sense: long, flat, cells with thin cuticle is equivalent to a shorter number of cells per unit of epidermal surface; short, high cells with thick cuticle to a high number of cells per unit of epidermal surface.

FIRMNESS AND RESISTANCE TO COMPRESSION

Table 4 shows mean values of firmness for the two years' tests. The difference of maturity is here much more patent than in puncture, as expected. Table 5 shows mean firmness values for the varieties involved in both years' tests, in values relative to Petomech II. Correlation between both series of means is highly significant. Broader variation of 1978 (C-P-I) tests accounts for the differences, but relative values are, like in the case of puncture resistance very constant.

The results of the mean values of compression resistance are shown in table 6. The second column is "traction force to rupture", in N/m. This is a new parameter, based on following considerations (Fig. 7):

Rupture of fruits in compression resulted always in a vertical crack, through a meridian (the same result as reported by Miles et al, 1968). Thus, if the hydrostatic theory holds, the traction caused by internal pressure (P_h, N/mm^2) that the outer fruit skin should resist, is:

$$F\ (N/mm) = P_h\ (N/mm^2) \times r\ (mm).$$

Knowing the pressure P_h at rupture, and the radius of the fruit, r, traction force F at rupture can be calculated.

Linear correlation coefficients were calculated, for individual fruits and for mean values of the varieties, for each of the following pairs of parameters, and with the following resulting values:

Correlation of:	for means of varieties (n=19)	for individual fruits (n=267)
puncture resistance with rupture pressure	0,681 **	0,477 **
" " with traction force	0,530 *	0,520 **
firmness with rupture pressure	0,568 *	0,438 **
" " traction force	0,731 **	0,598 **
puncture force with firmness	0,650 **	0,469 **

Nearly all are significant at the 1% level (**).

Thus, a great part of the variability in rupture pressure and traction force is attributable to puncture resistance and firmness differences, considered independently.

Multilineal regression of rupture pressure and traction force were calculated, for individual fruits and for mean values of the varieties. Both result in significant multiple correlation and regression coefficients, the equations being the following:

- for means of the varieties :

$z_p = 0,017 + 0,0363\, x_1 + 0,0040\, x_2$

$z_t = 0,5758 + 0,9974\, x_1 + 0,0006\, x_2$, being:

z_p = rupture pressure (N/mm^2)
z_t = traction force (N/mm)
x_1 = puncture force (N)
x_2 = firmness (N/mm)

Fig. 8 shows these planes, sectioned by some fixed values of x_2 (firmness). The higher dependance of traction force on puncture resistance, is apparent being largely independent of firmness, as was postulated.

Calculated for individual fruits, these multiple linear regression equations appear very similar.

Using all these results as a basis one can deduce that the resistance of ripe tomatoes to static pressure depends largely on their puncture resistance and their firmness. This is true for individual fruits in the varieties, as well as for mean varietal values of these parameters.

The fact that puncture and firmness show also in general correlation between them introduces some questions in the results, namely: are the puncture values dependant on the firmness of the fruits? or rather, in general do, firmer fruits and varieties also have a more resistant skin? There are some observations that confirm the second postulate:

One can find varieties combining low firmness with high or medium puncture resistance (H-324-1, Ventura) and others that combine low punc_ ture resistance with high or medium firmness (H-530, ES-58, Bulker, Dorchester) (see tables 1 and 4).

The se cond group (low puncture resistance) show lower impact resistance (see table 8) and the first group are intermediate in compression and impact resistance (tables, 6, 7, 8). Taking all the fruits and varieties into consideration, a high skin resistance will provide the tomato with good mechanical resistance, and this will be multiplied if combined with high firmness.

On the other part, low skin puncture values combiend with medium to low firmness (VF-145-21-4-s, tables 1 and 4) results in fruits with the lowest resistance to impact and compression (tables 6 and 7).

Therefore, we consider that there is only a combination of resistant skin and firm fruit in most of the varieties of processing tomato that are now in cultivation, but these characters can be independent (and are in fact in some of the varieties); they can be also independently measured with the procedures here reported; and they are related to genetically determined anatomical features, at least in what concernes the skin.

RESISTANCE PARAMETERS AND IMPACT DAMAGE

Preliminary tests of resistance of tomato fruits to impact, made with the pendulum, indicated that some varieties could resist without damage an impact of 0,7 N.m, but some others would be severely damaged with this impact. Thus, repeated impacts of 0,43 N.m, equivalent to 0,5-0,8 m of free fall of the fruit with mass 50-75 g were used. Table 7 shows the total number of impacts that would resist each of the varieties tested (1975 previous impact tests). These results showed some correlation of impact resistance with puncture resistance and firmness of the fruits.

Results of the 1978 (C-P-I) test are shown in table 8. Having calculated the correlation of this index I (no. of fruits with crack plus no. of fruits with severe damage, in 10 fruits per variety) and varietal mean values of mass puncture force and firmness, the following results were obtained:

- an important proportion (35%), (r=0,59) of the variability of index I can be attributed to variations in the mean mass of the fruits for each variety;

- another high proportion (22%, r= 0, 47) can be attributed to variation in mean puncture force, and only 2 % to variation in firmness. Fig. 9 shows the variation, for all the varieties tested, of mean values of free fall impact damage (index I) and mean values of puncture resistance, high puncture resistance corresponding to low I index. Some variability appears in this I index, the most apparent deviations corresponding to the extremely high mass of the fruits of the variety, or to extremely low firmness.

All this indicates the dependance of impact resistance of tomato varieties from the resistance parameters : puncture force and firmness, puncture force being more important in this case; but getting being most vulnerable those varieties which apart from low puncture resistance show either low firmness or high mass.

The free drop test, though perhaps more real, is only indicative to relate impact resistance with other parameters, such as puncture force and firmness -much more precise- and above all with only 10 fruits per variety.

Wider impact resistance studies will be made in future tests.

DISCUSSION

Differences in damage incidence in mechanical harvesting and handling of fruits are mainly time-temperature and maturity dependent (O'Brien et al 1978). Nevertheless, the importance of varietal differences is very high though not much recognized and very little studied.

The problem is that varietal values of physical properties parameters appear usually very inconsistent for different tests, enviromental conditions, cultures, etc. This is particularly the case for tests like probe penetration (i. e. Magness-Taylor) which combine different components of resistance (compression, rupture, tangential stress resistance, etc) measuring only one magnitude (penetration force). (Philouze, 1975).

Therefore, an effort must be made to : 1) use fundamental and well defined tests, and 2) maintain all the sources of variability (other than va riety in our case) as constant and well-known as possible. The variation of physical parameters with ambient conditions should then be studied comple mentarily. Therefore, further study will be needed to determine the depen dance of resistance parameters (in the case of processing tomatoes; skin puncture resistance and force-deformation parameters)on: temperature, air moisture, sun exposure, maturity evolution, and others.

In the results presented, consistent relative values of tomato resis tance parameters are obtained, although the conditions were positively different for different year's tests, which is apparent in the variation overall means.

Abnormal results will be obtained with varieties of a very different shape (for example VF-65, that is fairly firm and very skin-resistant, but doesn't break in compression like other varieties because of its very elon gated shape). Some different testing procedure, for firmness and rupture had to be used in these cases : force-deformation with spherical indenter is much more adequate than flat-plate compression in these cases.

Based on the high correlation coefficients obtained in all force-defor mation tests, a simplified measuring method may be used for determining great numbers of fruits, consisting of:

1) determine deformation for 4 to 6 levels of force (2 to 8 N) for 2 fruits;

2) for the rest of the fruits of the sample, determine only 2 points of force-deformation selected on the base of the first two fruits (i.e. 2 and 5 N, or 3 and 7 N) which are enough to calculate the slope of the correspon dent force-deformation relationship or firmness. It is evident that from these measurements, modulus of deformability or elasticity E can be com puted for each fruit and each variety applying Hertz theory. This would have the advantage of eliminating curvature differences between varieties and fruits, to arrive at a better defined parameter. Nevertheless, having attempted this procedure, important disadvantages arise : the measuring

of curvature radii is too laborious to be made in all fruits, and the computation of E introduces too many errors (in these radii, Poisson's modulus, etc), in the results.

The puncturing technique has proved appropriate for determining the resistance of the skin. All other sistems for measuring skin properties that need laborious preparation of skin samples seem too complicated for variability studies, where hundreds of measurements are to be taken. Apart from that, it is difficult to establish in each variety which part of the cell layers are to be taken as the skin: some varieties present a hypodermal zone that can be essential for skin resistance in the whole fruit and may be let behind in the probe-preparation.

Following the results presented, in the search for more mechanical damage resistant tomato varieties the trend should be to skins with thick and rounded epidermal cells, with thick and penetrating cuticle. However, evidence exists (Mel Chih-Yu Chu and Thompson, 1972) that these varieties would tend to be susceptible to cracking, if the characters indicated were combined with numerous layers of subepidermal cells (which in fact, is not necessarily so).

The shape of the tomato fruits (round or pear) appears to be not a relevant characteristic in the resistance of individual fruits. Usual indications of differences in damage percentages for these two types of fruits (O'Brien, 1976) should be related to specific varieties which show some different skin and firmness constitutions, size and maturity conditions.

SUMMARY AND CONCLUSIONS

With the procedure used in this research it is possible to detect significant differences in the mechanical properties: puncture resistance (N) and firmness (N/mm) between a great number of processing tomato varieties. The values are affected, in a similar way for all varieties, by various variables, such as temperature, maturity and culture conditions, but the mean relative values are very consistent.

Both parameters puncture resistance and firmness determine the resistance of ripe tomato fruits to rupture by pressure and by impact, being skin resistance, measured as puncture force, a resistance component more relevant than firmness.

A new concept of traction force F is introduced, being the maximum force attained at rupture by compression at the point of iniciation of a crack (maximum equatorial diameter) in terms of force per unit meridian length (N/mm), due to the hidrostatic pressure P_h (N/mm^2) originated by static compression of the fruit with radius r (mm). This traction force depends closely on skin resistance of the fruit.

There is a clear dependance of skin puncture force on following histological characteristics: roundness of the epidermal cells and thickness and penetration between cells of the cuticle, which can be used to predict the likely behavior of each variety to puncture.

Mean values are given, for a total of different processing tomato varieties, of puncture force (0,7-1,72 N), firmness (1,74-9,00 N/mm), rupture pressure (0,0421-0,0715 N/mm^2) and traction force (0,946-1,601N/mm).

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Table 2. - Mean values of puncture resistance (N) for the varieties involved in all tests (upper part) and for all the varieties (below) in relative values to Petomech II mean.

1976 (P)		1977 (CP)		1978 (C P I)	
Petomech II 1,06 =	1,00	Petomech II 0,86 =	1,00	Petomech II 1,52 =	1,00
H-4016	0,93	H-4016	0,95	H-4016	0,77
Ventura	0,92	Ventura	0,91	Ventura	0,82
Napoli	0,79	Napoli	0,90	Napoli	0,74
H-324-1	1,01	Red River	1,07	Petogro II	1,13
H-22-74	0,96	VF-134-2	1,05	Euromech	0,93
Mecheast 55	0,86	VF-317	1,02	Cal J[2, 3]	0,93
Roma VF	0,83	Cal J[2, 3]	0,99	Peto Early	0,88
Chef	0,66	VFN-8	0,96	H-324-1	0,86
VF-145-21-4-S[1, 2]	0,67	VF-316	0,86	Europeel	0,82
		Pieletty	0,84	H-30	0,82
		C-35[2, 3]	0,83	Hypeel 229	0,81
		VF-145-78 x79	0,79	Royal Chico	0,79
		VF-145-22-8	0,77	Florida MH-1	0,78
		Potomach	0,76	California	0,76
		VF-318	0,74	Río Grande	0,76
		C-34[2,3]	0,73	Cambella	0,76
		Chef[1,2]	0,70	C-34[2, 3]	0,73
		VF-145-21-4-S[1, 2]	0,69	Nova Super Roma	0,72
				H-1706	0,70
				Chico III	0,69
				Super California	0,69
				C-35[2, 3]	0,69
				Super Roma	0,69
				Roma VF	0,68
				Dorchester	0,67
				H-2274	0,63
				H-530	0,60
				ES-58	0,58
				Bulker	0,50

(1, 2) replicated 1976-1977

(2, 3) replicated 1977-1978

Table 1. - Mean values of puncture resistance (N) for all the varieties and all the tests.

1976 (P)		1977 (C-P)		1978 (C-P-I)	
Variety	Puncture force (N)	Variety	Puncture force (N)	Variety	Puncture force (N)
H-324-1	1,08	Red River	0,917	Petogro II	1,72
Petomech II	1,06	VF-134-1-2	0,902	Petomech II	1,52
H-22-74	1,02	VF-317	0,875	Euromech	1,42
H-4016	0,99	Petomech II	0,860	Cal J	1,42
Ventura	0,98	Cal J	0,849	Peto Early	1,34
Mecheast 55	0,91	VFN-8	0,826	H-324-1	1,31
Roma VF	0,88	H-4016	0,821	Europeel	1,25
Napoli	0,84	Ventura	0,783	H-30	1,25
Chef	0,70	Napoli	0,782	Ventura	1,24
VF-145-21-4-S	0,71	VF-316	0,744	Hypeel 229	1,23
		Pieletly	0,720	Royal Chico	1,21
		C-35	0,711	Florida MH-1	1,18
		VF-145-78x79	0,683	H-4016	1,18
		VF-145-22-8	0,660	California	1,16
		Potomach	0,657	Río Grande	1,16
		VF-318	0,638	Cambella 147/73	1,15
		C-34	0,630	Napoli	1,12
		Chef	0,603	C-34	1,11
		VF-145-21-4-S	0,595	Nova Super Roma	1,10
				H-1706	1,07
				Chico III	1,06
				Super California	1,06
				C-35	1,05
				Super Roma	1,05
				Roma VF	1,04
				Dorchester	1,00
				H-2274	0,96
				H-530	0,91
				ES-58	0,89
				Bulker	0,76
nº of fruits and data /mean:	10-50		15-75		10-50
Standard desviation of means:	0,02		0,02		0,03
Coef. of variation	0,15		0,18		0,14

Table 3. - Mean values of epidermal cells' parameters and puncture force of the fruits in the seven varieties tested (1976-P Lests).

Variety	puncture force(N)	cells width (μm)	cells height (μm)	cuticle thickness (μm)
Petomech II.	1,16	26,13	13,75	6,94
H-324-1	1,14	22,54	17,97	8,44
H-2274	1,09	25,58	12,81	6,41
Mecheast 55	0,95	25,42	12,40	5,94
Ventura	0,86	26,92	11,22	5,34
Napoli	0,73	31,54	11,19	5,75
Chef	0,68	28,88	7,69	4,81
number of determinations	5	30	8	8
Standard dev. of means	0,022	0,37	0,33	0,17
Coef. of variation	0,15	0,18	0,19	0,19
Coef. of correlation with puncture force		-0,818 ^{xx}	0,830 ^{xx}	0,825 ^{xx}

^{xx} Significant at 1% level.

Table 4.- Mean values of firmness (slope of the force-deformation line by flat plate compression of one side of the fruits), for the two years tested, N/mm.

1977 (C-P) Variety	N/mm
Petomech II	2,84
VF-317	2,84
H-4016	2,74
Red River	2,57
VF-134-1-2	2,55
VFN-8	2,43
Pieletty	2,38
Cal J	2,35
VF-145-22-8	2,26
VF-318	2,23
VF-145-21-4-S	2,15
VF-145-78 x 79	2,03
VF-316	1,92
C-34	1,86
Chef	1,86
Napoli	1,79
Ventura	1,76
C-35	1,76
Potomach	1,74
no. of fruits/mean :	12-17
Standard error of the means:	0,065
Coef. of variation :	0,20

1978 (C P I) Variety	N/mm
Peto Early	9,00
Cal J	8,20
Río Grande	7,38
H-4016	7,29
Petogro II	6,68
Petomech II	6,46
Europeel	6,30
Florida MH-1	6,11
ES-58	5,83
Euromech	5,69
H-530	5,65
H-30	5,40
Roma VF	5,28
Nova Super Roma	5,13
H-1706	5,09
Hypeel 229	4,39
Bulker	4,27
California	4,27
Dorchester	4,27
Super California	4,24
H-324-1	3,97
H-2274	3,89
Royal Chico	3,89
C-34	3,57
Ventura	3,22
C-35	3,17
Cambella	3,13
Super Roma	3,05
Napoli	3,03
Chico III	2,99
no. of fruits/mean :	10
Standard error of the means:	0,034
Coef. of variation :	0,23

Table 5.- Mean values of firmness (N/mm) for the varieties involved in both tests (upper part), and for all the varieties (below) relative-values to Petomech II mean.

1977 C P

	N/mm
Petomech II 2,84 =	1,00
H-4016	0,96
Cal J	0,83
C-34	0,65
Napoli	0,63
Ventura	0,62
C-35	0,62
VF-317	1,00
Red River	0,90
VF-134-1-2-	0,89
VFN-8	0,86
Pieletty	0,84
VF-145-22-8	0,80
VF-318	0,79
VF-145-21-4-S	0,76
VF-145-78 x 79	0,71
VF-316	0,68
Chef	0,65
Potomach	0,61

1978 (C P I)

	N/mm
Petomech II 6,46 -	1,00
H-4016	1,12
Cal J	1,27
C-34	0,5[illegible]
Napoli	0,49
Ventura	0,50
C-35	0,45
Peto Early	1,39
Río Grande	1,1[illegible]
Petogro II	1,03
Europeel	0,98
Florida MH-1	0,95
ES-58	0,90
Euromech	0,88
H-530	0,87
[illegible]-30	0,84
Roma VF	0,82
Nova Super Roma	0,79
H-17[illegible]	0,79
Hypeel 229	0,68
Bulker	0,66
California	0,66
Dorchester	0,66
Super California	0,65
H-324-1	0,61
H-22-74	0,60
Royal Chico	0,60

Table 6.- Mean values of rupture pressure (N/mm) and traction force to rupture (n/mm) for 19 varieties. 1977 (CP) test.

Variety	Rupture pressure (N/mm^2)	Traction force (N/mm)
VF-134-1-2	0,0715	1,601
Petomech II	0,0633	1,613
Red River	0,0578	1,273
H-4016	0,0578	1,290
Pieletty	0,0559	1,291
VF-145-22-8	0,0559	1,406
Ventura	0,0568	1,114
Cal J	0,0558	1,376
VF-317	0,0519	1,612
VF-316	0,0519	1,418
Potomach	0,0510	1,137
VF-145-78 x 79	0,0500	1,356
Napoli	0,0498	0,946
VF-318	0,0496	1,272
VFN-8	0,0480	1,560
C-34	0,0477	1,196
Chef	0,0472	1,175
C-35	0,0456	1,242
VF-145-21-4-S	0,0421	1,137

nº of fruits/variety :	12-17	12-17
Standard desviation of the means :	0,0001	0,06
Coef. of variation :	0,20	0,18

Table 7. Mean number of impacts with the pendulum (15º = 0,43 N . m) till crack or break of the fruit (1975 preliminary test).

Variety	nº of fruits	mean number of 0,43 N . m
H-2274	41	3,64
Petomech	39	3,41
Mecheast 55	33	3,03
Napoli	40	2,87
H-324-1	44	2,70
Ventura	34	2,48
H-4016	40	2,40
Roma VF	44	2,22
VF-145-21-4-S	28	2,20
Chef	39	1,95

Table 8. - Susceptibility to free fall impact indeces (I=no. of cracked fruits plus severely damaged fruits) for 30 varieties, in relation to mean mass (g) mean puncture resistance (N) and firmness (N/mm) (10 fruits/variety)

Variety	Index I	mean mass (g)	mean puncture resistance (N)	firmness (N/mm)
Cal J	0	69	1,42	8,20
Petogro II	1	70	1,72	6,68
Petomech	1	62	1,45	6,46
Río Grande	1	93	1,16	7,38
Euromech	2	59	1,42	5,69
Royal Chico	2	58	1,21	3,89
Super California	2	52	1,06	4,24
Nova Super Roma	2	51	1,10	5,13
H-1706	2	52	1,07	5,09
Hypeel 229	2	51	1,23	4,39
H-324-1	3	49	1,17	3,97
H-30	3	111	1,25	5,40
California	3	53	1,16	4,27
Super Roma	4	55	1,05	3,05
Ventura	4	46	1,45	3,22
Dorchester	5	58	1,07	4,27
H-4016	6	59	1,18	7,29
C-35	7	85	1,05	3,17
Europeel	7	60	1,25	6,30
Peto Early	7	89	1,34	9,00
Napoli	7	55	1,12	3,03
H-2274	9	115	0,96	3,89
Roma VF	9	63	1,04	5,28
C-34	9	77	1,11	3,57
H-530	12	138	0,91	5,65
Chico III	12	57	1,06	2,99
Bulker	13	129	0,76	4,27
Florida MH-1	14	115	1,18	6,11
ES-58	19	170	0,89	5,83
Cambella	20	68	1,11	3,13

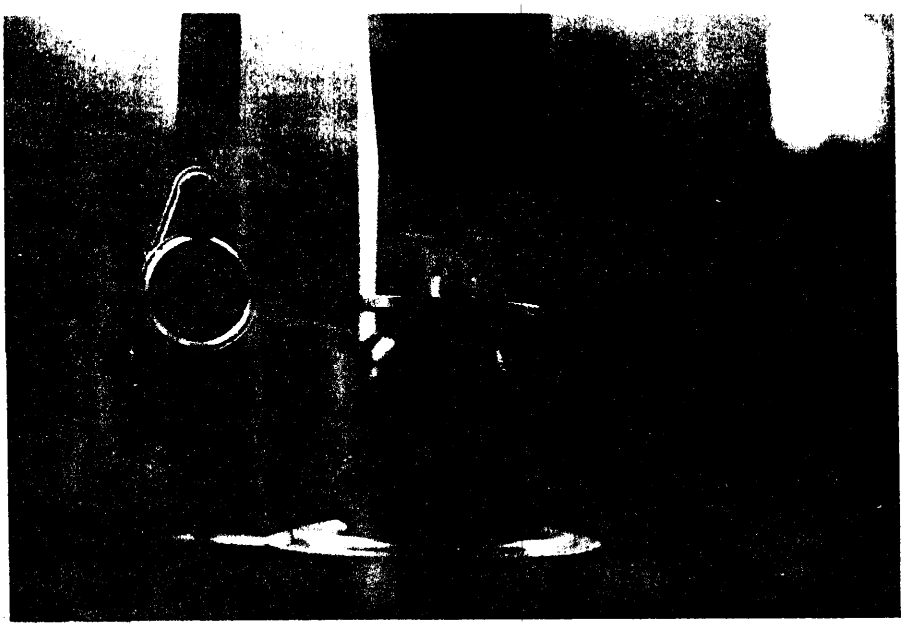


Figure 1. - Force-deformation measurement of whole intact tomatoes with a Chatillon testing machine.

Figure 3. - Measurement of puncture re_ sistance of tomatoes with a Chatillon tes_ ting machine, provided with a die of 0, 45 mm of diameter.

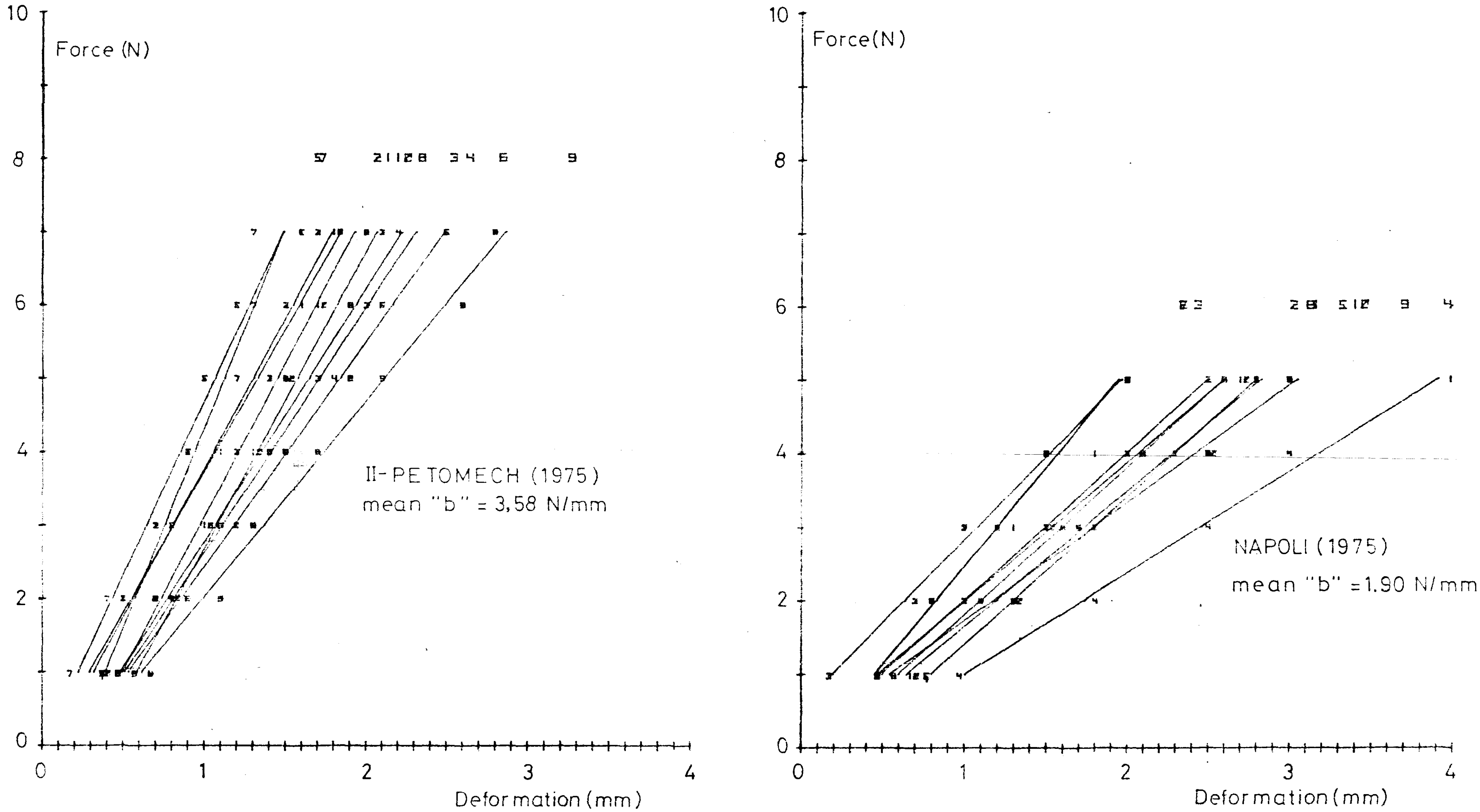


Fig. 2. - Computer force-deformation regression lines, for two different varieties (1975). Values of "b" (regression coefficient = slope of the lines) indicate the firmness of each fruit; mean "b" the mean firmness of the variety.

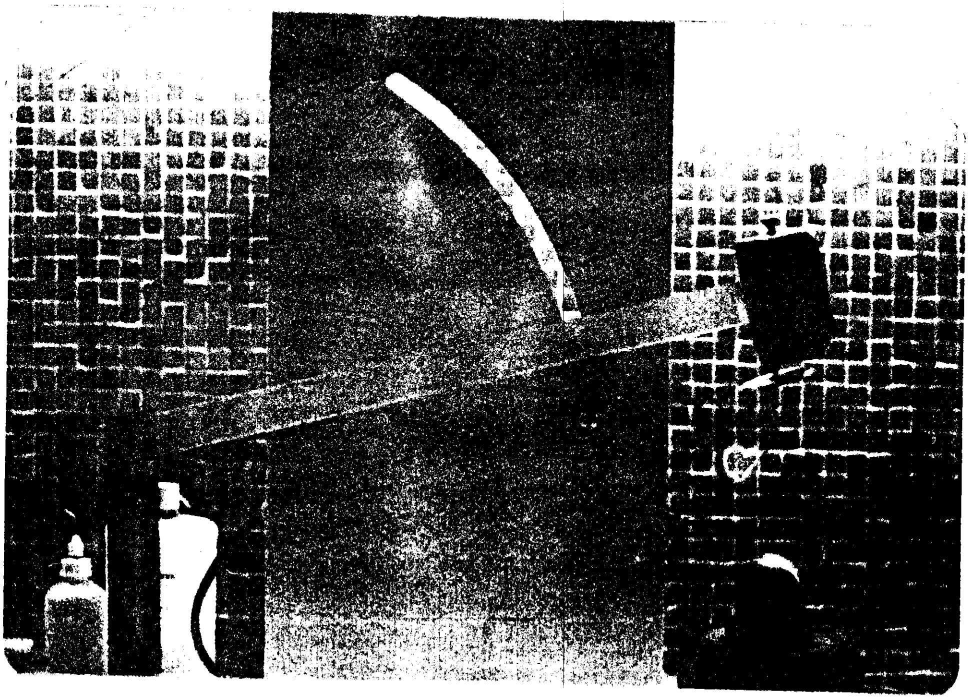
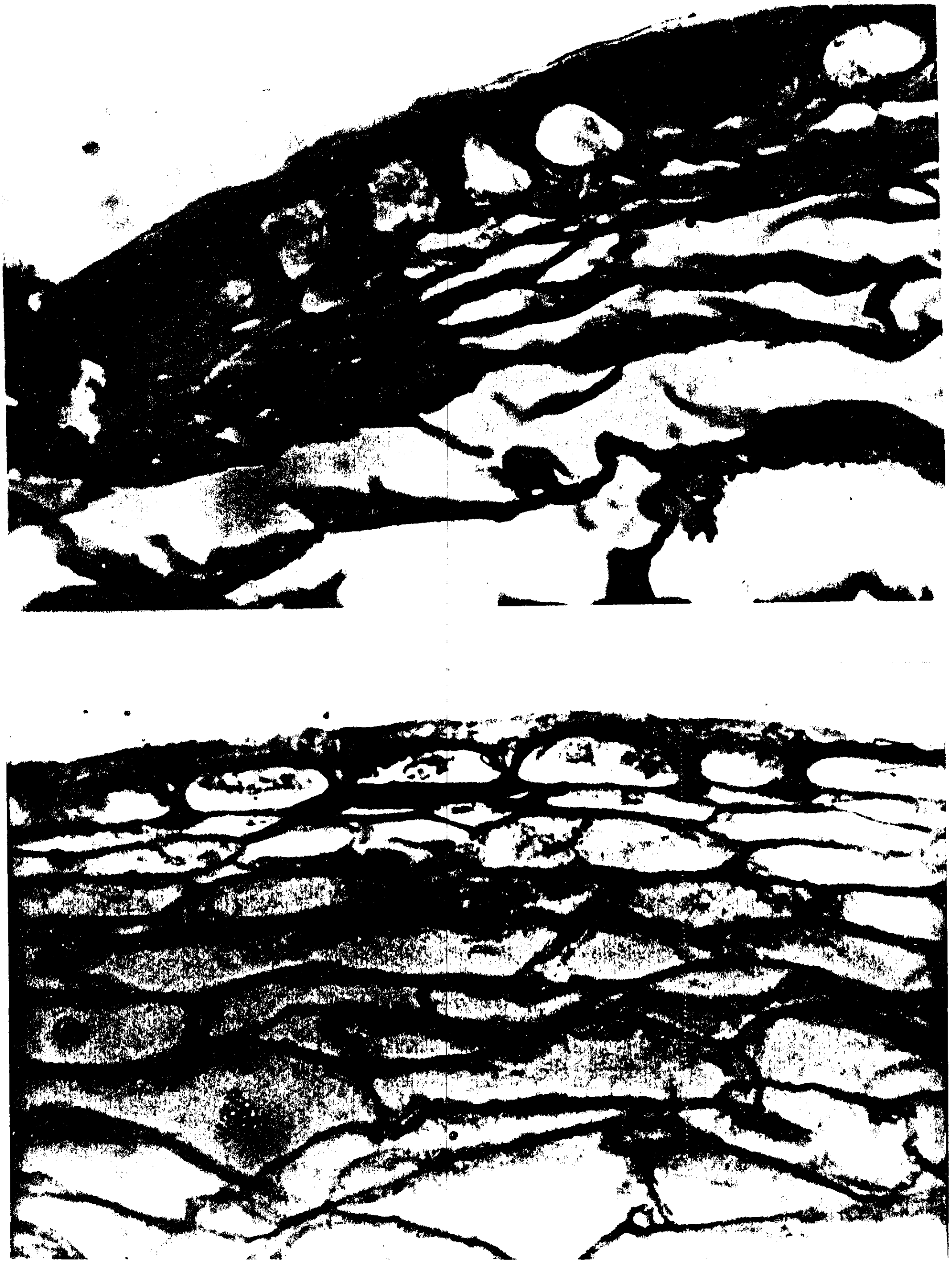


Figure 4. - Pendulum for determining impact resistance of tomatoes. Angle of the pendulum arm with the horizontal determines the energy and velocity of each level of impact.



a)

b)

Figure 5. - Skin microphotographs (40 x) of two of the varieties tested (1976--P) : a) higher resistant (H-324-1) and b) lower-resistant (Napoli). Note the shape of the first-layer cells and the thickness and penetration (a) of the cuticle.

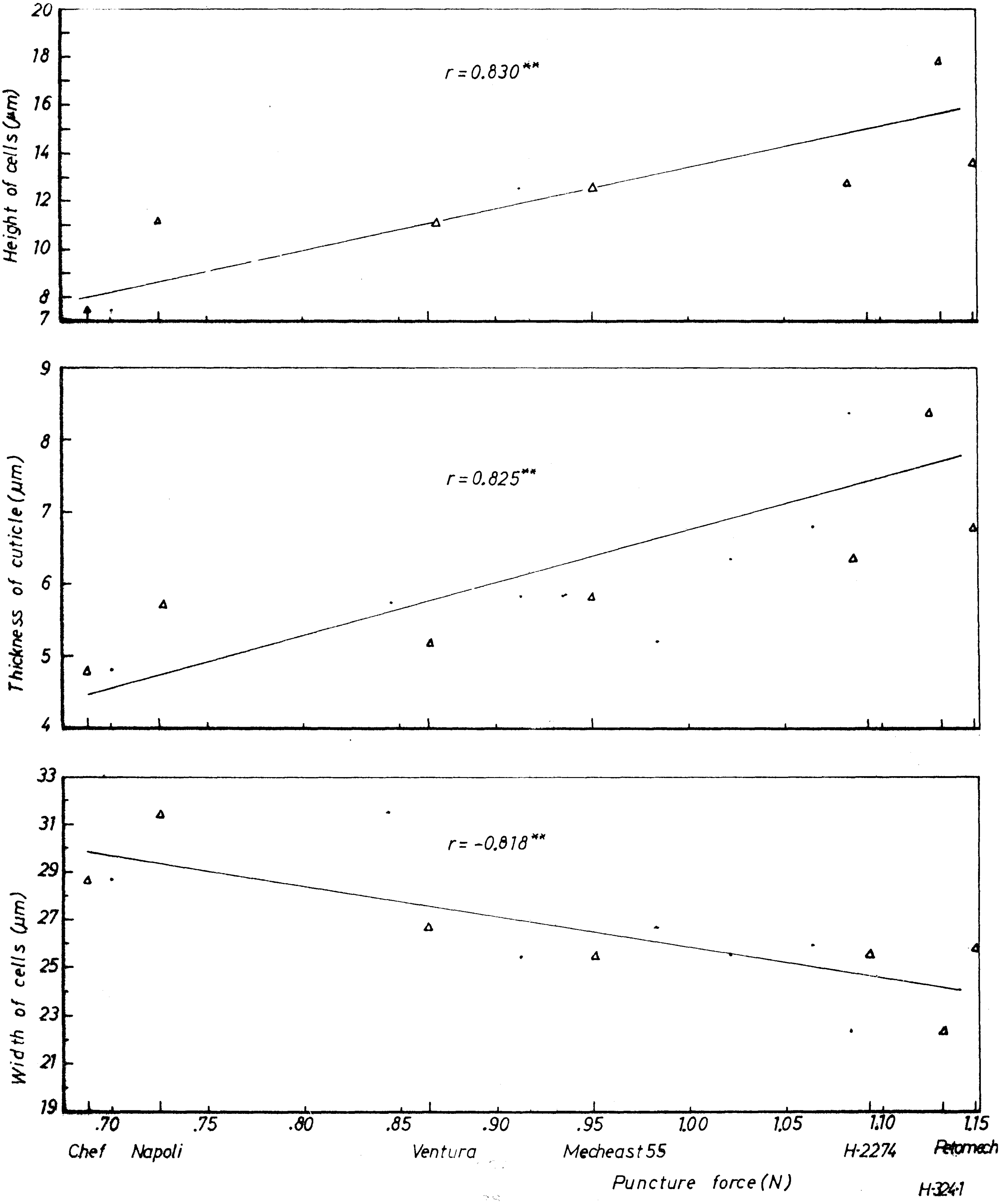


Figure 6. - Correlation between height of cells, thickness of cuticle and width of cells (µm) with puncture resistance (N) : ▲ individual fruit values (means of 5 punctures); • variety values (means of 50 punctures).

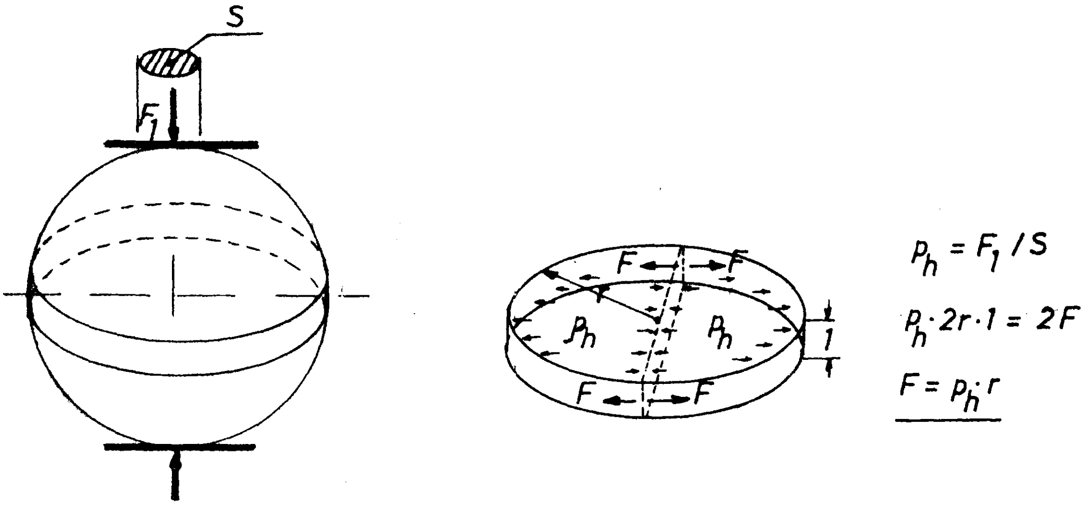
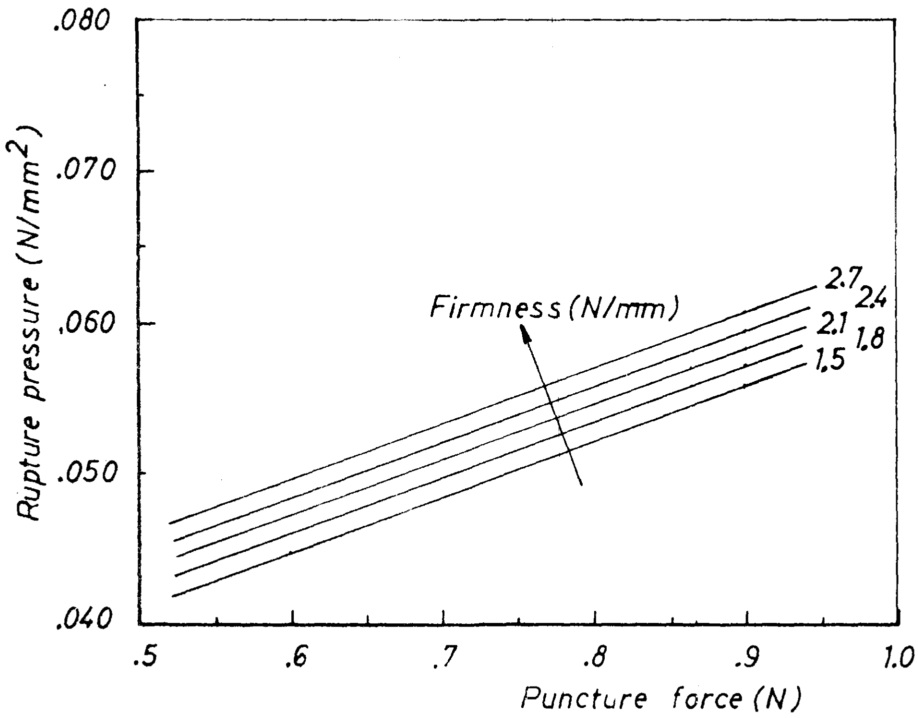


Figure 7. - Pressure applied to the surface S of the fruit produces traction force F (N/mm)= P_h (N/mm^2) x r (mm) on the equatorial zone of the fruit skin.



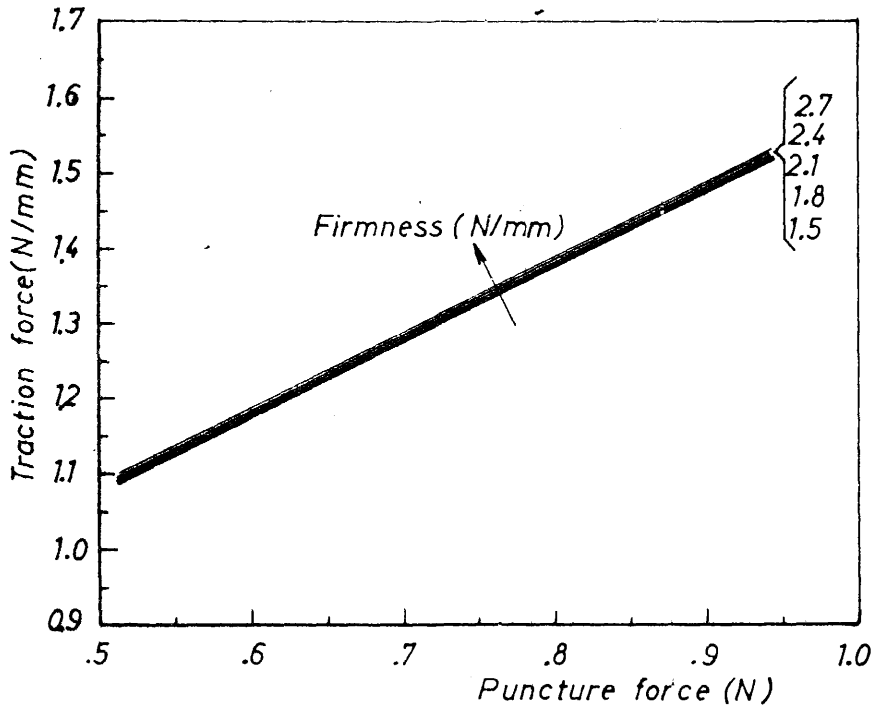


Figure 8. - Dependance of rupture pressure and traction force of tomato fruits on skin puncture force and firmness. Note that traction force depends largely only, and highly, on skin puncture force.

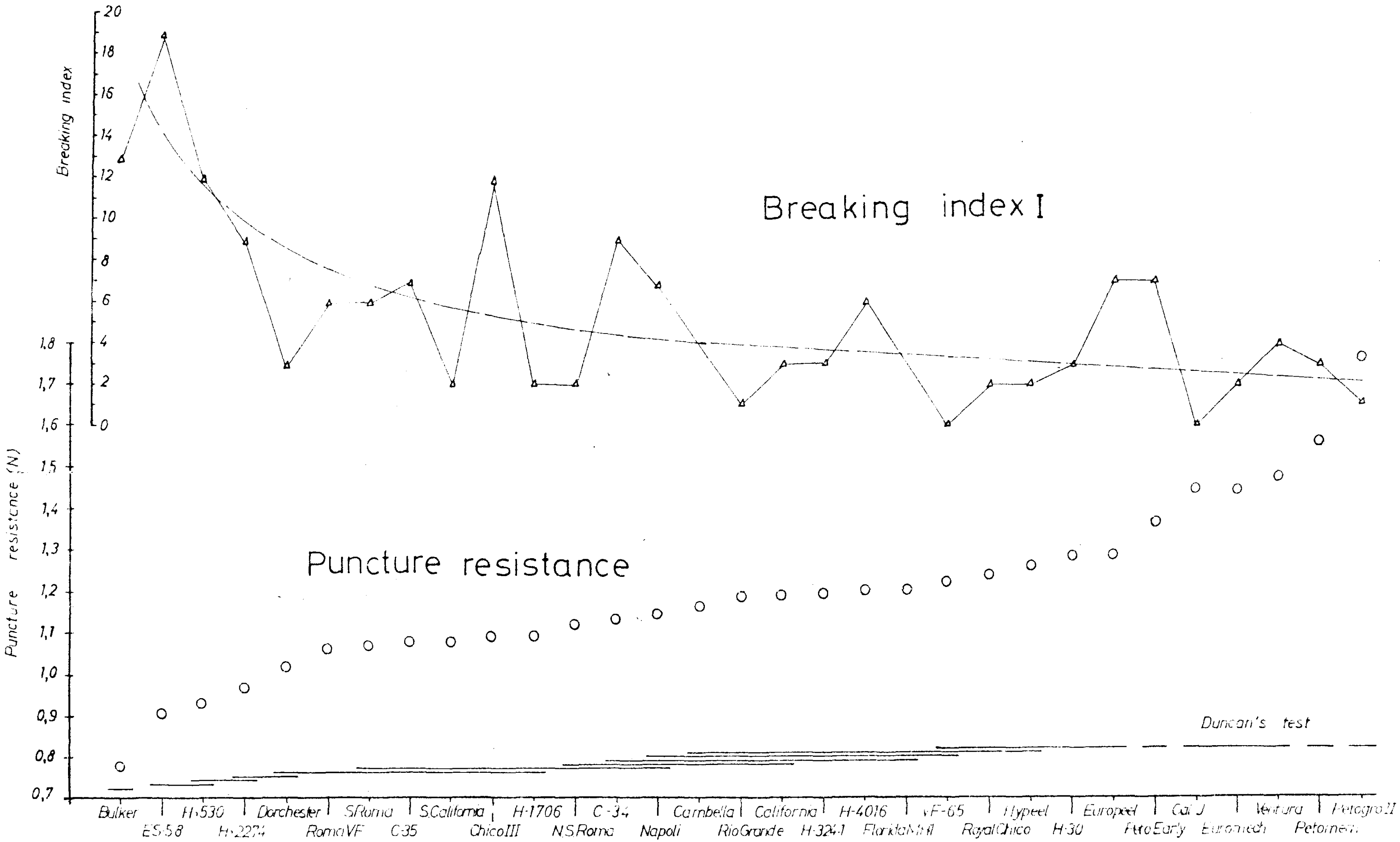


Figure 9. - Mean values of free fall impact damage susceptibility index I and skin puncture resistance (N) for 1978 (C-P-I) processing tomato varieties. High puncture resistance values correspond to low I indeces.